NsG-357

STELLAR ROTATION AND THE POSITION OF THE METALLIC-LINE STARS IN THE COLOR-MAGNITUDE DIAGRAM

Peter A. Strittmatter and Wallace L. W. Sargent

University of California, San Diego

Received. . . . .

[redacted]

ABSTRACT

Baschek and Oke (1965) have shown that, after deblanketing corrections are made, the Am stars in the Hyades cluster lie to the left of the main sequence in the color magnitude diagram; we find that the Am stars in the Coma and Praesepe clusters behave similarly. This is interpreted as being due to the low intrinsic rotation of the metallic line stars and is shown to be consistent with recent theoretical work (Roxburgh and Strittmatter 1966a,b) which indicates that, at a given color, more rapidly rotating stars will appear more luminous. A method is suggested for determining a "zero rotation" main sequence and hence for estimating the intrinsic rotational velocity and aspect of individual stars in clusters.

[redacted]

I. Introduction

Recently, Baschek and Oke (1965) have shown that, after their B-V colors have been corrected for excess line blanketing, the Am stars in the Hyades lie to the left of the main sequence in the color-magnitude diagram. This observation is of considerable interest because Abt (1961) has advanced powerful arguments to show that the Am stars are intrinsically slow rotators. According to recent theoretical work by Roxburgh and Strittmatter (1966a,b), slowly rotating stars should lie to the left of the main sequence defined by normal, rapidly rotating, A-stars and Baschek and Oke's discovery offers an opportunity to check quantitatively the predictions of the theory.

It is obviously important to inquire whether the Am stars in other clusters behave similarly to those in the Hyades. Using information already in the literature, we have been able to show that Baschek and Oke's result is also true of the Am stars in Praesepe and in the Coma Cluster. Before demonstrating this, we first consider Baschek and Oke's deblanketing procedure and show how their results can be used to obtain the "deblanketed" colors of Am stars from their measured B-V and U-B.

It is well known that, as is illustrated in Figure 1, the Am stars lie below the normal, main sequence line in the two-color diagram. Several authors have conjectured that this is due to the increased line-blanketing caused by the abnormal number and strength of the metallic-lines rather than to differences in luminosity or atmospheric structure between the Am stars and normal, main sequence stars. Baschek and Oke determined θ_{eff} and log g for several normal and Am stars by comparing their continuous energy distributions and Balmer-line profiles with those calculated from model atmospheres.

The continuum scans were, in all cases, corrected for the presence of metallic lines by using high-dispersion spectra. They found that the Am stars have similar values of log g to normal main sequences stars. However, in a plot of θ_{eff} against B-V similar to Figure 2, the metallic-line stars fell systematically off the line defined by normal stars. This must be attributed to the effect of excess line blanketing on the observed values of B-V. Baschek and Oke used a diagram similar to Figure 2 to read off the corrected value of B-V, $(B-V)_c$, which a metallic line star would have if it were a normal star having the same θ_{eff}. In turn $(B-V)_c$ was read into the normal curve in the two-color diagram to obtain $(U-B)_c$. This was done by Baschek and Oke for two of their Am stars, τ UMa and 63 Tau, both of which lie significantly to the right of the normal relation in Figure 2. They found that the "deblanketing vectors" for these two stars were approximately parallel (see Figure 1) and hence assumed that the same vector could be used to deblanket all Am stars. They were thus able to obtain corrected colors for several Am stars in the Hyades (including 63 Tau itself) from the UBV photometry of Johnson and Knuckles (1955). The result quoted earlier, namely that the Am stars lie to the left of the Hyades main sequence, then followed.

Baschek and Oke's result depends on whether or not the deblanketing vectors of all Am stars are indeed parallel. It is possible to test whether this is so because Conti (1965) has derived values of θ_{eff} for five additional Hyades Am stars. Conti obtained his estimates of θ_{eff} from a relationship between $(B-I)_6$ in the six-color system and the values of θ_{eff} obtained by Melbourne (1960). The band B on the six-color system is not the same as the band B in the UBV system; the index $(B-I)_6$ is much less sensitive to line blanketing than B-V. Fortunately, the relationship between θ_{eff}

and B-V obtained from Melbourne's data is almost identical to that given by Baschek and Oke for the range of θ_{eff} under consideration. Hence the values of θ_{eff} given by Conti can be used to obtain $(B-V)_c$ for his five Am stars from Baschek and Oke's relationship which has been plotted in Figure 2. The deblanketing vectors thus obtained, together with those for 63 Tau and τ UMa are shown in Figure 1.

There is clearly a considerable scatter in the directions of the vectors in Figure 1. In view of the paucity of data, this was attributed to random errors in the determinations of θ_{eff} and a mean slope α, illustrated in Figure 1, was calculated from the relation

$$\alpha = \frac{\sum \left\{ (B-V) - (B-V)_c \right\}}{\sum \left\{ (U-B) - (U-B)_c \right\}}$$

In the following section we apply the mean deblanketing vector to calculate $(B-V)_c$ for Am stars in the Hyades, in Praesepe and in the Coma Cluster; we then obtain the corrected positions for these stars in the color-magnitude diagram of their respective cluster.

II. Metallic-line Stars in Clusters

(a) The Hyades

The mean deblanketing vector was used to obtain the corrected B-V colors of the Hyades stars listed in Table 1. The numbers designating the star in column two are those of van Beuren (1952). The values of v sini in the last column are due to Conti (1965) with the exception of that for 68 Tau which is taken from Treanor (1960). The absolute magnitudes of the Am stars in Table 1 and of the normal stars in Figure 3 were obtained by combining Johnson and Knuckle's (1955) UBV photometry with the distance moduli given by

Heckman and Johnson (1956). Two stars in Table 1, HR1519 and 16 Ori, were not included in Heckman and Johnson's list; for them we adopted moduli calculated from van Beuren's distance determinations.

A color-magnitude diagram for the Hyades upper main sequence is shown in Figure 3. In this diagram all stars (e.g. HR1403) which are known to be double-line spectroscopic binaries have been omitted. The diagram shows that when their colors have been corrected for blanketing, the Am stars lie along the lower edge of the main sequence close to the zero age main sequence (Sandage 1957), which is the solid line in Figure 3. This is the result obtained by Baschek and Oke and we shall discuss its implications later. We note, however, that had we derived individual values of $(B-V)_c$ for the stars in Table 1 from Conti's values of θ_{eff} instead of using the mean deblanketing vector, the positions of the Am stars in Figure 3 would have been changed slightly; however, the qualitative result would be unaltered.

(b) The Coma Cluster

Weaver (1952) lists eight Am stars in the Coma Cluster. One of these, Trumpler 104, is a double-lined spectroscopic binary and has been omitted from Table 2. This table gives for each of the remaining seven stars the values of V, B-V and U-B measured by Johnson and Knuckles (1955), and the values of v sini obtained by Kraft (1965). The positions of the seven Coma Am stars in the two-color diagram are shown in Figure 4. Johnson and Knuckles found that the F-type stars in Coma have a slight ultraviolet excess relative to those in the Hyades. We have therefore corrected the Coma Am stars, not to the normal line in Figure 4, but to one displaced from it by $\delta(U-B) = 0.035$ and $\delta(B-V) = 0.02$. Figure 4 shows in any case that, judged from their positions in the two-color diagram, the Am stars in Coma (with the exception of Trumpler 62) do not have such large line-blanketing effects as those in the Hyades. It may be noted that the standoff from the normal line in Figure 4 is correlated with the v sini's given in column eight of Table 2. Columns five and six of Table 2 list the values of $(B-V)_c$ and $(U-B)_c$ obtained by applying the mean deblanketing vector. Figure 5 gives the corrected positions of the Coma Am stars in the color-magnitude diagram. We see that like the Hyades, the Coma Am stars fall systematically to the left of the main sequence - the solid line in Figure 5. There are two Ap stars plotted in Figure 5, Trumpler 146 (17 Comae) and Trumpler 160 (21 Comae) which have values of v sini of 15 and 55 km/sec respectively. This may also be taken as evidence that slowly rotating stars fall to the left of the main sequence; this point will be referred to again in the final section.

The Coma cluster has a distance of about 80 pc and a diameter of about 7 pc; this will introduce some scatter into Figure 5 since, unlike the Hyades, no corrections have been applied to individual stars to allow for their spread in distance. However, unless the Am stars are systematically placed towards the far side of Coma, this will not alter the conclusion that the Am stars fall to the left of the main sequence.

(c) Praesepe

According to Bidelman (1956) Praesepe contains nine Am stars. Two of these, numbers 229 and 300 in Klein Wassink's (1927) list, are double-lined spectroscopic binaries and have not been treated in what follows. Two other stars KW40 and KW538 were not included in Johnson's (1952) UBV photometry of the cluster. The remaining five stars have been plotted in the two-color diagram (Figure 4) and their corrected colors, visual magnitudes and v sini's (the latter due to Treanor 1960) are listed in Table 3. The color-magnitude array of Praesepe is given in Figure 6. Once again the Am stars lie to the left of the main sequence when their colors have been corrected for excess blanketing. In Praesepe several of the Am stars lie above the turn-off point as defined by the normal stars and the possibility that the more luminous ones are evolved cannot be excluded; we shall return to this point later.

III. The Effects of Rotation

In the previous section it was shown that, once blanketing corrections have been made, the metallic line stars in three clusters lie below the main sequence as defined by the normal cluster members. Abt (1961) has demonstrated that the Am stars are probably all members of close binary systems and has produced evidence which indicates that the observed rotational velocities are correlated with the orbital periods. It may therefore be assumed that the orbital and rotation axes tend to be aligned. Since the metallic line stars have generally low values of v sini, even when they are members of binary systems in which the orbital plane is inclined at a small angle to the line of sight, it is clear that these stars are intrinsically slow rotators. We now ask whether the position of the Am stars in the color magnitude diagrams is due to their low angular momentum.

At first sight this seems an unlikely hypothesis since it is a well known theoretical result that rotation should decrease the total luminosity of a star. However, rotation also decreases a star's effective temperature. Its position in the color magnitude diagram will thus depend on the relative change in these parameters. Sweet and Roy (1953) and Roxburgh, Griffiths, and Sweet (1965) have considered the structure of uniformly rotating upper main sequence stars and Roxburgh and Strittmatter (1966c) subsequently evaluated the observational parameters M_V and B-V for these models as functions of angular momentum. Roxburgh and Strittmatter (1966a,b) have also discussed the structure of non-uniformly rotating stars in which there is no meridional circulation; these stars are necessarily magnetic. In all cases it was found that rotating stars viewed pole-on appear brighter, and those viewed equator on less bright, than non-rotating stars of the same mass. From any angle, a rotating star will appear redder than its non-rotating counter-part. However, a rotating star of a given color will appear brighter than a non-rotating star of the same color but, of course, of different mass. Indeed the degree of brightening at a given color turns out to depend almost entirely on intrinsic rotational velocity and hardly at all on the mass or aspect of the star. That is, the main sequences for stars rotating with a given velocity are almost coincident and are approximately parallel to the zero rotation main sequence. The situation is illustrated schematically in Figure 7. The shift ΔM_V from the zero rotation main sequence is given in terms of the rotational velocity v by an expression of the form

$$\Delta M_V = \varkappa v^2 \tag{1}$$

where $\varkappa$ is a constant depending on the model (c.f. Roxburgh and Strittmatter 1966b). Theoretical estimates for $\varkappa$ derived from the various models are listed in Table 4. For non-uniformly rotating stars we give two values of $\varkappa$; the first is for slow rotators in which the magnetic forces are negligible, the second, for stars in more rapid rotation, in which the magnetic and centrifugal forces are comparable. Thus, $\varkappa$ is a slowly varying function of v but, since the total range of variation is small, the expression (1) will be left in its present form. The transition velocity between the two cases depends on the mass of the star; details are given by Roxburgh and Strittmatter (1966a).

Clearly the above discussion provides a logical connection between the low intrinsic rotation of the metallic line stars and their position in the color magnitude diagram. Since apparent rotational velocities and luminosities are known for both the Am and the brighter normal stars in the three clusters discussed earlier, it is possible to derive an empirical estimate of $\varkappa$. We will return to this point but will consider first an independent observational test of the theory which avoids use of the Am stars.

In a study of the normal main sequence stars in Praesepe, Strittmatter (1966) has shown that, if the stars are divided into groups according to color, then, within any group, the stars with above average v sini tend also to be brighter. Values of $V - \langle V \rangle$ were plotted against $(v \sin i)^2 - \langle (v \sin i)^2 \rangle$, where $\langle\ \rangle$ denotes an average over any color group; a straight line, slope $\varkappa'$ was fitted to the data. If it is assumed that within any group, the rotation axes are randomly oriented, we have (Chandrasekhar and Münch 1950)

$$\langle (v \sin i)^2 \rangle \simeq 2/3 \ \langle v^2 \rangle \tag{2}$$

Since we expect a relation of the form (1) to exist between ΔM_V and v^2, a similar <u>mean</u> relation should exist between ΔM_V and $(v \sin i)^2$; the quantity $\varkappa'$ provides an estimate of the gradient in this relation, and hence, from equation (2), an estimate of $\varkappa$. This latter quantity is listed in Table 4, and is subject to an internal error of about 15 - 20 percent. From the values of $\langle (v \sin i)^2 \rangle$ and the derived estimate of $\varkappa'$, the mean shift in magnitude was obtained for each group, and hence, from the known values of $\langle V \rangle$, the approximate magnitude of a non-rotating star at each group color. This gave an estimate of the zero rotation main sequence for Praesepe, the dashed line in Figure 6. By fitting a line of the same gradient to the sequence defined by the slowly rotating stars of later spectral type (that is, B-V $\gtrsim$

0.45) in the Hyades and Coma clusters, approximate zero rotation main sequences were obtained for these clusters also. These are the dashed lines in Figures 3 and 5, respectively. We note that in both cases the Am stars lie along the estimated zero rotation sequence and show little scatter about it. The Am stars in Praesepe show more scatter but, since most of them are to the left of the turn off point as defined by the normal stars, this may be attributed to evolutionary effects. For this reason Am stars in Praesepe are of little use in providing an estimate of $\varkappa$.

The Am stars in the Hyades and Coma clusters may, however, be used to estimate $\varkappa$. We consider the Hyades first. With the exception of 68 Tau, the Am stars lie in a relatively small interval of B-V. We therefore compute the average value of M_v and $(v \sin i)^2$ for both the Am and the normal stars in this interval. If we assume that rotation axes are randomly orientated, relation (2) enables us to obtain the average v^2 in each category; an estimate of $\varkappa$ is then given by

$$\varkappa = \frac{\langle M_v \rangle_{normal} - \langle M_v \rangle_{m\ell}}{\langle v^2 \rangle_{normal} - \langle v^2 \rangle_{m\ell}} \qquad (3)$$

Alternatively, we may consider a wider range of colors and measure the shifts ΔM_v of individual stars from the estimated zero-rotation main sequence. The value of $\varkappa$ may then be determined by substituting ΔM_v for M_v in equation (3); this method increases the number of stars in the sample. The results from the two determinations of $\varkappa$ are closely similar and their mean is given in Table 4. The rotational velocities used are those given by Kraft (1965); the star VB141 is not included in Kraft's list and therefore could not be considered in these estimates. The star VB72 was also excluded since it appears to be evolved.

The metallic line stars in the Coma cluster occur in a region of the color magnitude diagram in which there are few normal stars. We therefore measured shifts ΔM_V from the estimated zero rotation main sequence for stars bluer than B-V = 0.41, thereby increasing the number of normal stars in the sample. The rotational velocities used are again due to Kraft (1965). The stars 107, 125 and 130 in Trumpler's (1930) list were omitted from the calculation as they may be evolved. An estimate of κ was obtained as before and is listed in Table 4. It is, however, of doubtful significance owing to the paucity of the sample of normal stars.

The data assembled in Table 4 indicates that the models of non-uniformly rotating stars give results for κ which are in fairly close agreement with those obtained from observations. Though the scatter in the values of κ derived from cluster color-magnitude diagrams is considerable (about 40 percent) the difference between these estimates and that predicted from models of uniformly rotating stars is significantly large. Although more detailed stellar models, including accurate opacity and nuclear generation data, are necessary, it is extremely unlikely that more precise calculations will alter the predicted value of κ sufficiently to affect this basic conclusion.

IV. Summary and Discussion

We summarize our main findings as follows:

(1) After deblanketing corrections are made, the metallic line stars in the Hyades, Praesepe and the Coma cluster lie to the left of the main sequence band defined by the normal stars. This is taken to be an intrinsic property of the Am stars.

(2) The position of the Am stars in the color magnitude diagram is due to their low angular momentum compared with stars of similar mass. This cir-

cumstance enables us to determine empirically the approximate position of the zero rotation main sequence for clusters in which Am stars are found.

(3) Observational evidence for the effects of rotation are in rough quantitative agreement with estimates obtained from models of non-uniformly rotating stars.

Since the peculiar A stars are thought to be slow rotators (Deutsch 1965, Searle and Sargent 1965) we would also expect these stars to lie to the left of the main sequence when they are found in clusters. Results given by Baschek and Oke (1965) for the two stars β Cr B and 52 Her indicate that the deblanketing procedure for the Ap stars is more complicated than that for the Am stars and must be done separately for each star. However deblanketing effects decrease with increasing temperature and we may expect the hotter stars to have normal colors. Eggen (1963) has shown that the Am and Ap stars in the Hyades moving group lie in a band in the color magnitude diagram which intersects and lies generally above the sequence for normal stars. We suggest that, if blanketing effects are taken into account, this band will swing about its high magnitude end until it lies along the lower edge of the main sequence. This would be a direct consequence of the low angular momentum of the Ap and Am stars. In this connection we note that the Ap star 17 Comae lies close to the normal line in the two color diagram (Figure 4) and is therefore probably unblanketed; it also lies close to the zero rotation main sequence for the Coma cluster (Figure 5) and has the low observed rotational velocity v sini of 15 km/sec. The Ap stars may thus provide a means of extending to bluer colors the empirical zero-rotation main sequence derived from the Am stars.

Both 17 Comae and 68 Tauri are examples of 'blue stragglers', that is of blue stars on the main sequence above the turnoff point defined by the normal stars. A possible explanation is that these 'blue stragglers' are slow rotators, and that the other stars of similar mass have been shifted to the red because of their rotation. Such an explanation is compatible with the observations for the Hyades and the Coma cluster. It would, however, imply that the age determinations based on the cluster turnoff point need revision. Since a non-rotating star has a shorter lifetime on the main sequence than a totating star of the same mass, the blue stragglers provide an upper bound to the age of the cluster, provided of course that all the cluster members were formed at essentially the same epoch. It is also possible that the empirical determination of the zero age main sequence (Sandage 1957) will require correction for the effects of rotation.

A method for differentiating observationally between slowly rotating stars and rapid rotators seen pole-on has been suggested elsewhere (Roxburgh, Sargent, and Strittmatter 1966). It is applicable principally to stars in clusters and depends on ΔM_V , the shift in magnitude at a given color from the zero-rotation main sequence. The intrinsic rotational velocity of the star may then be obtained from equation (1). Our work has shown that the Am stars provide a good estimate of the zero-rotation main sequence, the determination of which is essential to the method. By combining results for several clusters in which Am stars are found, it should be possible to derive an empirical zero-rotation, zero-age main sequence.

This work arose out of discussions at the AAS-NASA Symposium on Magnetic and other Peculiar and Metallic Line Stars held at the Goddard Space Flight Center, Greenbelt, Maryland on 8-10 November 1965. The work was supported by the National Science Foundation. One of us (P.A.S.) is indebted to the Commonwealth Fund, New York for the award of a Harkness Fellowship. This work has also been supported in part by NASA through Grant NsG-357.

REFERENCES

Abt, H. A. 1961, Ap. J. Supple., 6, 37.

Baschek, B., and Oke, J. B. 1965, Ap. J., 141, 1404.

Bidelman, W. P. 1956, P. A. S. P., 68, 318.

Chandrasekhar, S., and Münch, G. 1950, Ap. J., 111, 142.

Conti, P. 1965, Ap. J. Supple., 11, 47.

Deutsch, A. J. 1965, Paper read at A.A.S.-N.A.S.A. Symposium, Greenbelt, Maryland

Eggen, O. J. 1963, A. J., 68, 697.

Heckmann, O. and Johnson, H. L., 1956.

Johnson, H. L. 1952, Ap. J., 124, 477.

Johnson, H. L., and Knuckles, L. F., 1955, Ap. J., 122, 209.

Klein Wassink, W. J. 1927, Groningem Pub. No. 41.

Kraft, R. P. 1965, Ap. J., 142, 681.

Melbourne, W. G. 1960, Ap. J., 132, 101.

Roxburgh, I. W., Sargent, W. L. W., and Strittmatter, P. A. 1966, Observatory, in press.

Roxburgh, I. W., and Strittmatter, P. A. 1966a, M. N. in press.

____________________ 1966b, M. N. in press.

____________________ 1966c, Zt. f. Astr. (in press).

Roxburgh, I. W., Griffiths, J. S., and Sweet, P. A. 1965, Zt. f. Astr., 61, 203.

Sandage, A. R. 1957, 125, 435.

Searle, L., and Sargent, W. L. W. 1965, Paper read at A.A.S.-N.A.S.A. Symposium, Greenbelt, Maryland.

Strittmatter, P. A. 1966, Ap. J., (in press).

Sweet, P. A. and Roy, A. E. 1953, M. N. 113, 701.

Treanor, P. J. 1960, M. N., 121, 503.

Trumpler, R. J. 1930, Lick Obs. Bull., 14, 154.

van Beuren, H. C. 1952, B. A. N. <u>11</u>, No. 432.

Weaver, H. E. 1952, Ap. J. <u>116</u>, 541.

TABLE 1

Metallic-line Stars in the Hyades

Star	VB No.	θ_{eff}	B-V	U-B	$(B-V)_c$	$(U-B)_c$	M_v	vsini
60 Tau	38	0.685	0.320	0.102	0.312	0.016	2.83	15
63 Tau	45	0.64	0.296	0.135	0.225	0.064	2.50	<10
68 Tau	56	0.54	0.050	0.060	0.030	0.035	1.28	<30
81 Tau	83	0.620	0.259	0.097	0.185	0.075	2.37	15
HR 1519	112	0.574	0.187	0.125	0.097	0.076	1.93	<10
16 Ori	130	0.616	0.242	0.143	0.180	0.084	2.12	20

TABLE 2

Metallic-line Stars in the Coma Cluster

Trumpler No.	Name	(B-V)	(U-B)	$(B-V)_c$	$(U-B)_c$	V	vsini
62	8 Com	0.167	0.147	0.102	0.076	6.27	<12
68	HD 107168	0.177	0.094	0.170	0.087	6.67	95
82	HD 107513	0.275	0.026	0.275	0.026	7.42	50
139	HD 108486	0.163	0.096	0.154	0.090	6.76	30
144	HD 108642	0.179	0.109	0.160	0.088	6.54	<12
145	HD 108651	0.207	0.088	0.195	0.078	6.65	<12
183	22 Com	0.108	0.096	0.080	0.068	6.29	8

TABLE 3

Metallic-line Stars in Praesepe

Klein Wassink No.	HD No.	B-V	U-B	$(B-V)_c$	$(U-B)_c$	V	vsini
224	73618	0.193	0.142	0.142	0.088	7.32	70
276	73711	0.160	0.131	0.115	0.082	7.54	<45
279	73709	0.201	0.153	0.142	0.088	7.70	<45
286	73730	0.190	0.127	0.152	0.090	8.02	<45
350	73818	0.323	0.112	0.260	0.045	8.71	80

TABLE 4

Determinations of the Constant $\varkappa$

Source of Estimate	$\varkappa \times 10^5$
Models of uniformly rotating stars.	0.2 - 0.3
Models of non-uniformly rotating stars:	
(a) Slow rotators.	1.65
(b) Rapid rotators.	1.35
Normal stars in Praesepe.	1.1
Am stars in the Hyades.	1.7
Am stars in the Coma cluster.	1.4

CAPTIONS FOR FIGURES

Fig. 1 Two-color diagram for the Am stars observed by Baschek and Oke and by Conti. The arrows show the corrections which must be applied to the observed colors of each star in order to obtain the color corresponding to effective temperature. The mean line used to obtain corrected colors for other Am stars is also illustrated.

Fig. 2 Baschek and Oke's mean relation between θ_{eff} and B-V for normal stars (filled circles) is shown by the solid line. The diagram illustrates how the Am stars of Figure 2 depart from this relation.

Fig. 3 Color-magnitude diagram for the Hyades cluster showing the effect of correcting the colors of the Am stars. The solid line is the zero-age main sequence; the dashed line is the estimated zero-rotation main sequence.

Fig. 4 Two-color diagram for the Am stars in Praesepe and in the Coma cluster.

Fig. 5 Color-magnitude diagram for the Coma cluster showing the effect of correcting the colors of the Am stars. The solid line is the sequence of normal stars and the dashed line is the estimated zero-rotation main sequence. Stars 146 and 160 are Ap stars with small v sini.

Fig. 6 Color-magnitude diagram for Praesepe showing the effect of correcting the colors of the Am stars. The dashed line is the estimated zero-rotation main sequence.

Fig. 7 Schematic color-magnitude diagram showing the effect of rotation. The pole-on and equator-on main sequences for stars with given rotation velocity v are the lines pp and ee respectively. Stars observed at O, will have masses corresponding to non-rotating main sequence stars found at P and E according as they are seen pole-on or equator-on respectively.

Fig 2

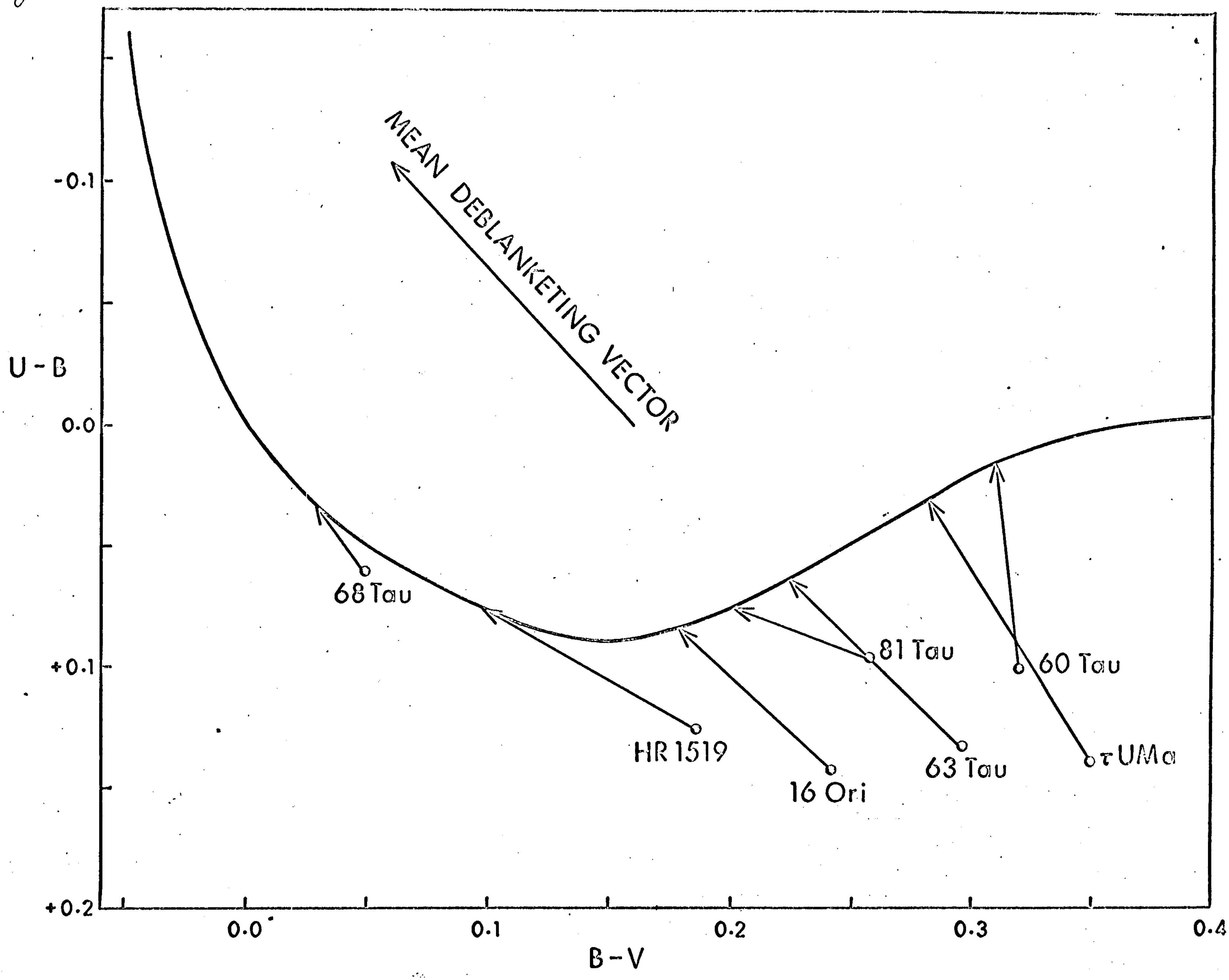

MEAN DEBLANKETING VECTOR
68 Tau
HR 1519
16 Ori
81 Tau
63 Tau
60 Tau
τ UMa
U - B
-0.1
0.0
+0.1
+0.2
B - V
0.0
0.1
0.2
0.3
0.4

Fig 2

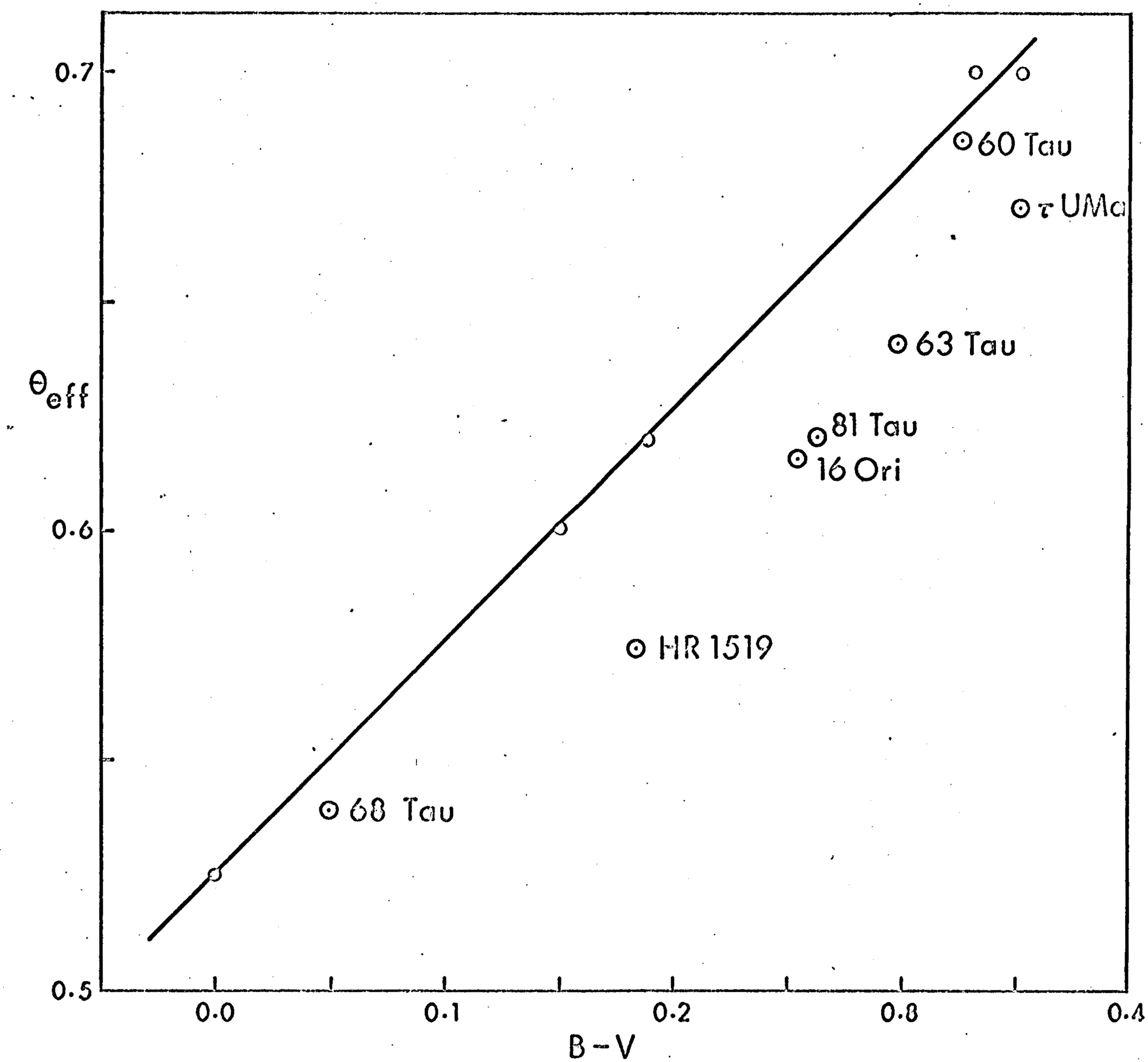
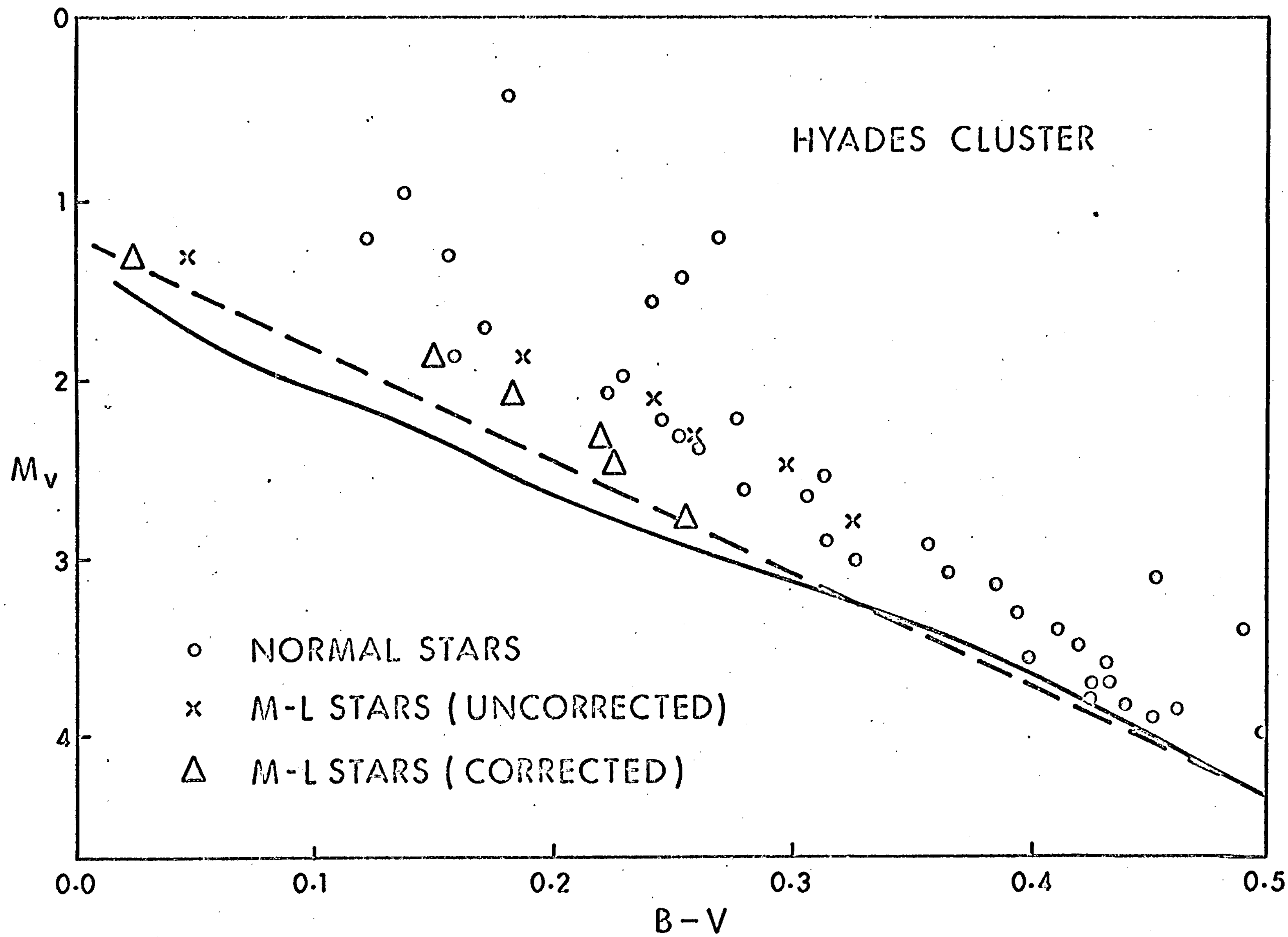
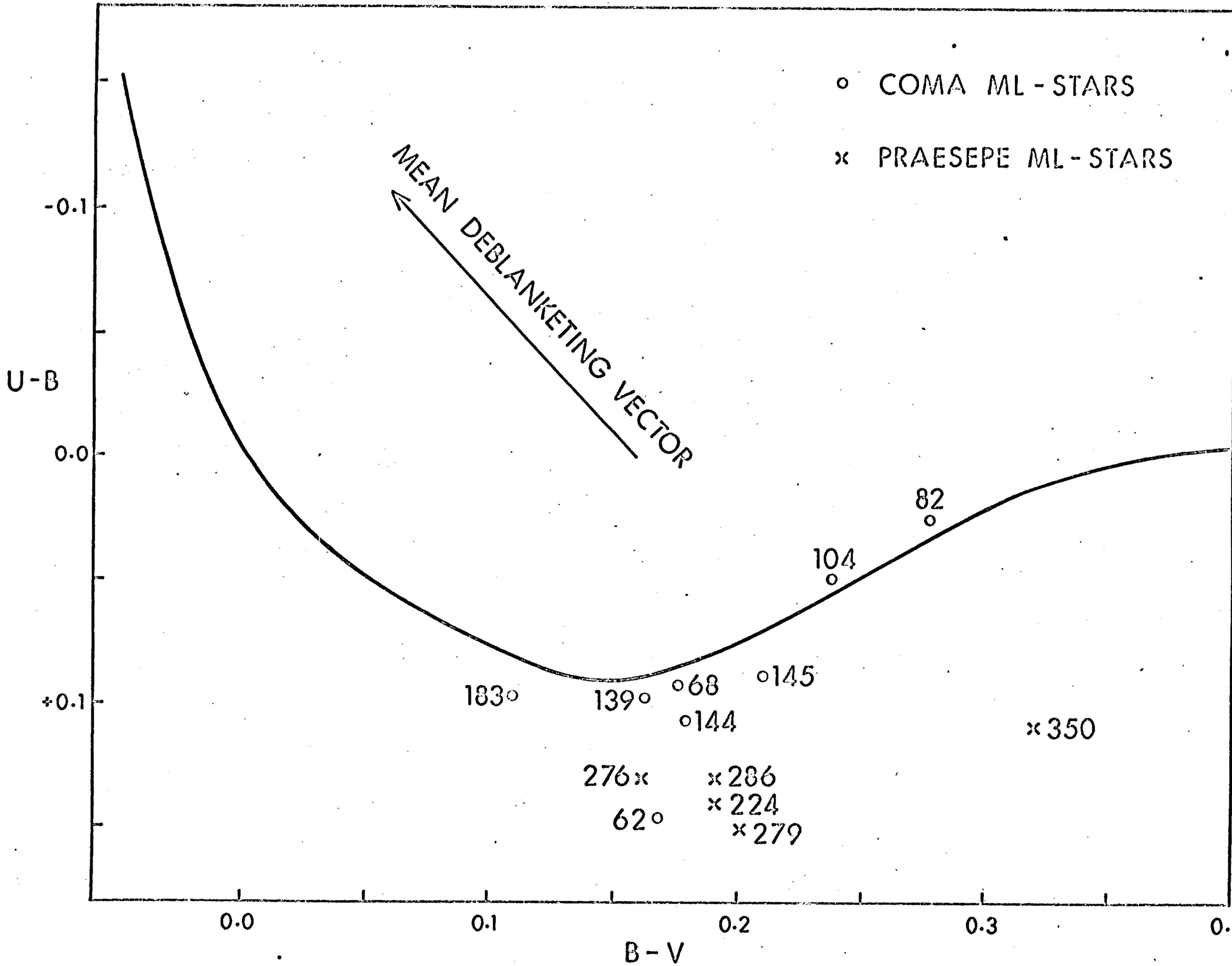

0.7
0.6
0.5
Θ_{eff}
0.0
0.1
0.2
0.8
0.4
B − V
60 Tau
τ UMa
63 Tau
81 Tau
16 Ori
HR 1519
68 Tau

Fig 3



HYADES CLUSTER
NORMAL STARS
M-L STARS (UNCORRECTED)
M-L STARS (CORRECTED)
M_V
B − V
0
1
2
3
4
0.0
0.1
0.2
0.3
0.4
0.5

Figure 9



○ COMA ML-STARS
× PRAESEPE ML-STARS
MEAN DEBLANKETING VECTOR
U-B
-0.1
0.0
+0.1
B-V
0.0
0.1
0.2
0.3
0.4
82
104
145
68
139
144
183
350
276
286
224
62
279

Figure 5

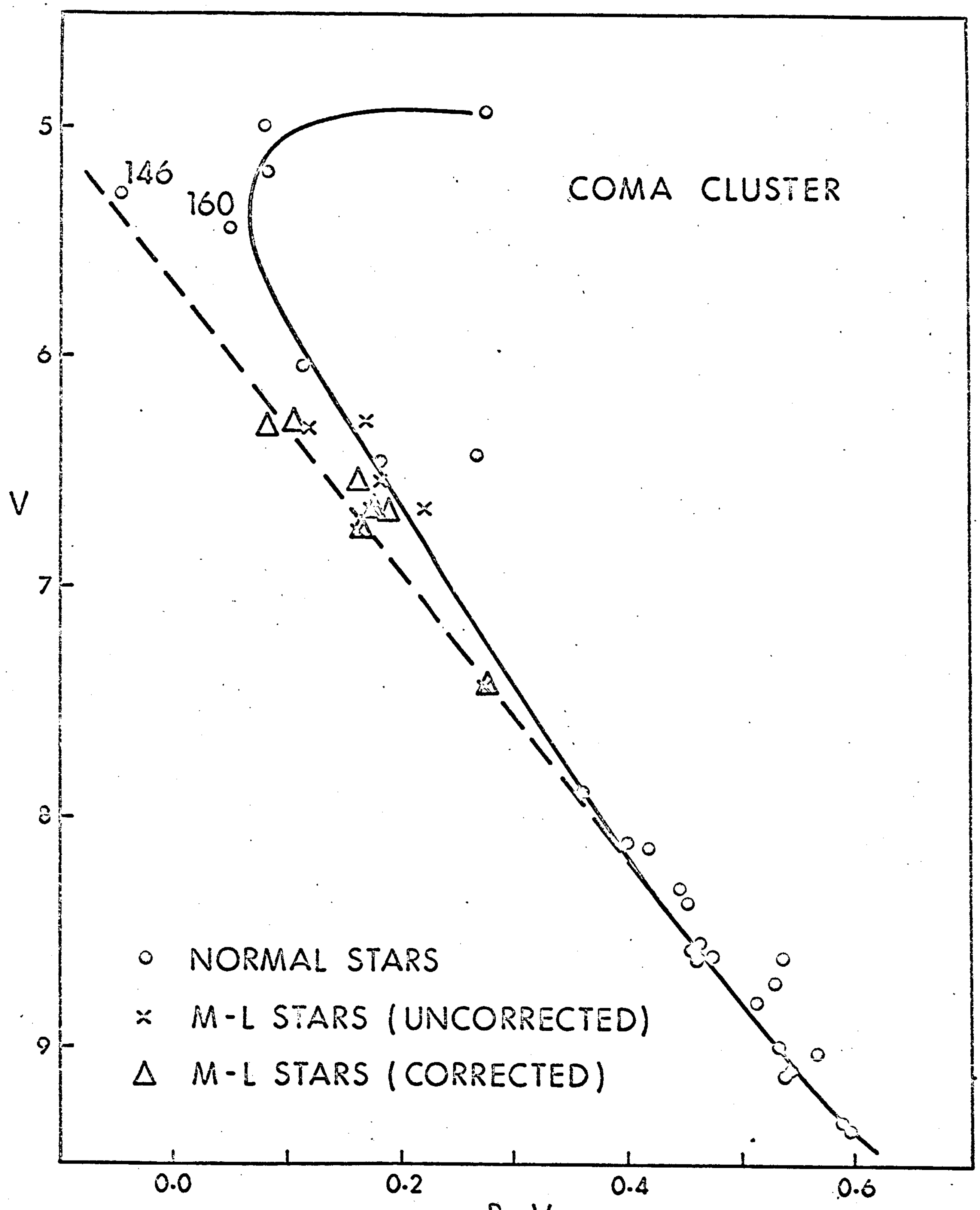

COMA CLUSTER
146
160
V
B-V
5
6
7
8
9
0.0
0.2
0.4
0.6
NORMAL STARS
M-L STARS (UNCORRECTED)
M-L STARS (CORRECTED)

Fig 6

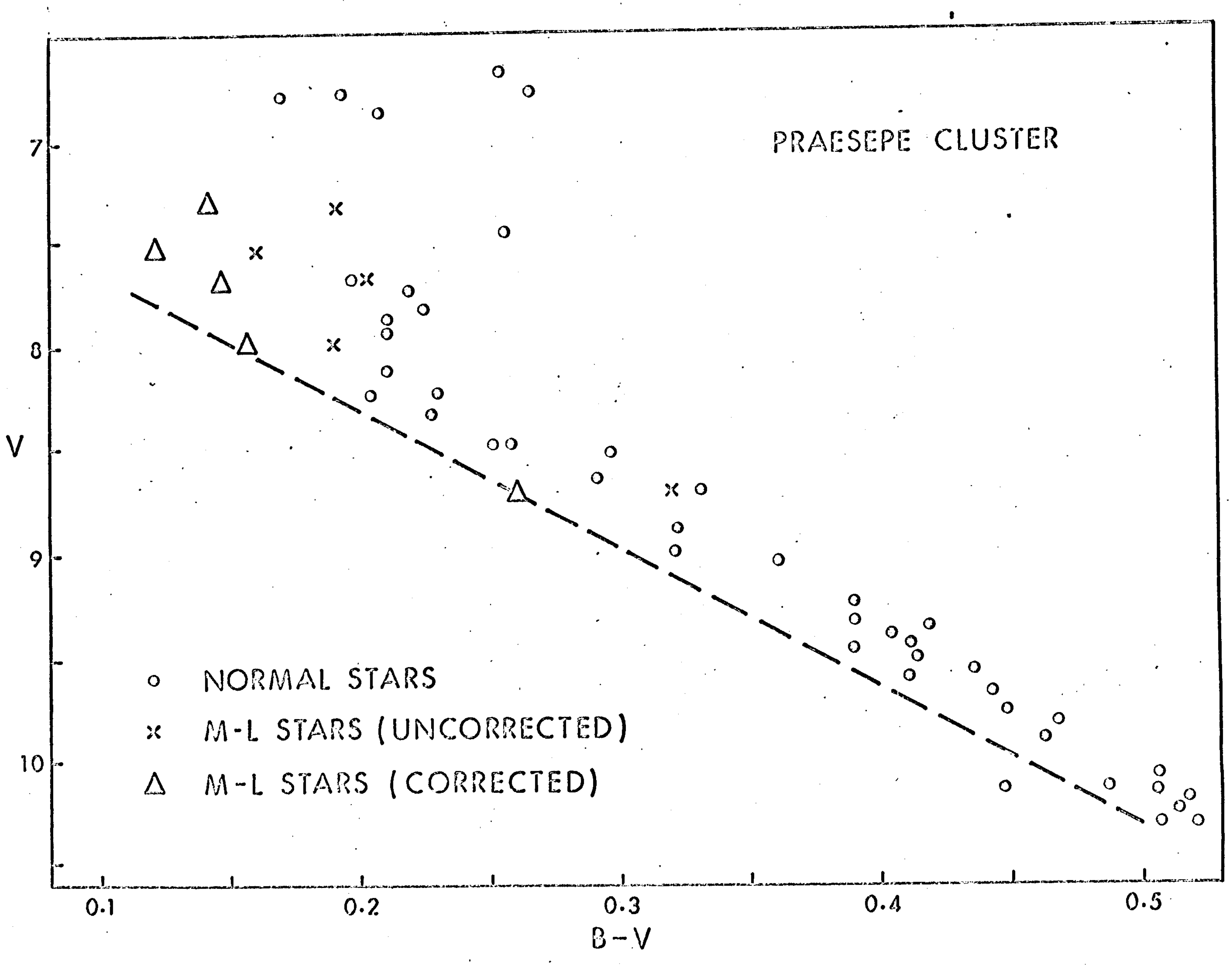
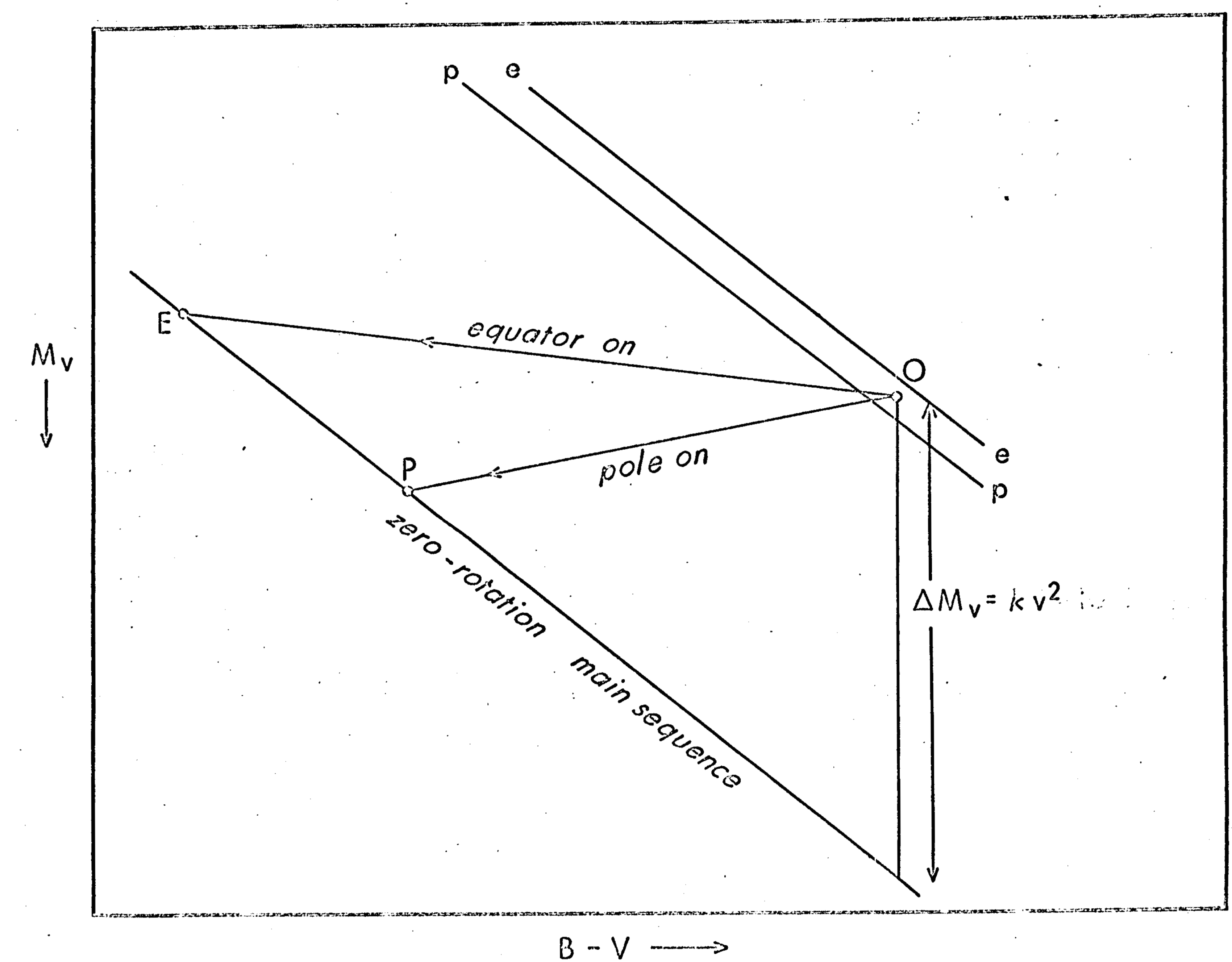

PRAESEPE CLUSTER
V
7
8
9
10
0.1
0.2
0.3
0.4
0.5
B−V
NORMAL STARS
M-L STARS (UNCORRECTED)
M-L STARS (CORRECTED)

Fig 4



p
e
E
equator on
O
e
p
M_v
P
pole on
zero-rotation
main sequence
$\Delta M_v = k v^2$
B - V